A distribution pattern of cadmium, gadolinium and samarium in *Phaseolus vulgaris* (L) plants as assessed by dynamic neutron radiography

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Abstract

The qualitative and semi-quantitative distributions, presumably apoplast transport patterns for the Gd, Sm and Cd were investigated in the primordial leaf tissues of the bean using dynamic neutron radiography. According to the applied 3D, 2D images and the pixel count distribution histograms of the considered gray levels, peculiar distribution patterns were postulated for the elements. Main and lateral vascular systems for Gd, the cell walls as well as intercellular spaces for Sm and the main leaf vein for Cd assumed to be the apoplast transport spaces and volumes. © 1999 Elsevier Science B.V. All rights reserved.

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1. Introduction

The visualization of the uptake, long distance translocation and accumulation pattern of elements in plants are important to clarify their function in a plant’s life.

The cadmium uptake, translocation and distribution are influenced by the pH, ionic strength, metal concentration of the nutrient medium and quantity of available organic compounds as well as plant species and phenological stages [1–4]. For the Cd uptake a model was set up [5]. The uptake, translocation and distribution of gadolinium and samarium and related physiological purposes have been far less studied in comparison with those of cadmium. The samarium and gadolinium concentrations in fruit and other plant tissues correlate with those determined in the soil [6,7]. The involved physiological functions seem to be the interaction with Ca\textsuperscript{2+}, and other signaling pathways as well as with gene expressions [8–11].

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VII. APPLICATIONS III
To our knowledge qualitative picture images on the distribution patterns of Cd, Gd and Sm have not yet been recorded. It would be of great help to further clarify the roles and function of these elements in plant systems. In this study using dynamic neutron radiography (DNR) distribution patterns of these element in the primordial leaf of bean, in tissue level, at a time scale has been imaged, recorded and analysed in vivo and in situ.

2. Material and method

Bean plants (Echo Elit variety) were grown in a specially designed aluminum cassette which was filled with D$_2$O (heavy water) during the measurement. Then 1 cm$^3$ D$_2$O containing 1.6 mg Gd and Sm and 2.6 mg Cd, respectively, was dropped with a syringe on the adaxial surface of the main vein. The high neutron absorption of Gd, Sm and Cd enables the DNR imaging of the distribution patterns of these elements in the neutron transparent D$_2$O. During the DNR imaging process the plants at primordial phenological stage were being kept in a plant rearing unit placed in the neutron beam and received photosynthetically active light radiation intensity of 200 $\mu$E m$^{-2}$ s$^{-1}$.

The thermal neutron flux $\Phi$, at the sample position was $10^8$ cm$^{-2}$ s$^{-1}$ with a beam diameter of 150 mm. The radiography images were converted into light by NE 426 converter screen and detected by a $10^{-4}$ lux TV 1122 type television camera making a 40 ms imaging cycle with a $\sim 100 \mu$m resolution. The DNR images were displayed on a monitor, recorded and stored by a S-VHS recorder. In order to explore the information on the elemental distribution revealed by neutrons, transmitted through the plants, the image analysis programs, Sapphire 5.05, made by Quantel and Imane 1.4, made by KFKI were used. For image analysis 800 images were integrated and beam shading correction was applied.

3. Results

3.1. Gadolinium distribution

A solution of Gd in D$_2$O (1.6 mg Gd in D$_2$O) was prepared and dropped onto the surface of the main vein of the adaxial surface of the primordial bean leaf. This point of time was designated as $t = 0$ and is clearly visible in Fig. 1a in 3D diagrams and in Fig. 1d in 2 D diagrams obtained from the DNR images. Then the apoplast movement was observed at the 30th minute (Fig. 1b, and e) and the 60th minute (Fig. 1c and Fig. 1f). The Gd apoplast transport mainly took place in the main vein and then in the lateral vascular systems. The simultaneous and uneven penetration frontier of the Gd into the intercostal mesophyll tissues from the 30th minute was clearly observable (Fig. 1b, and Fig. 1e). This type of Gd movement even more manifested itself at $t = 60$ min (Fig. 1c, and f).

The images were quantified using pixel count distribution histograms (areas) of the gray levels in 50–110 intensity range. The results are summarized in Fig. 2. The areas in the interval of 50–70 gray levels pixels can only be observed at $t = 0$ min. These areas of lower gray levels agree with the information based on neutron-beam attenuation pattern caused by the Gd drop, and converted into a characteristic light photon pattern. For the 60th minute observation, within the confines of 70–88 gray levels, the number of pixels exceeded those measured for $t = 0$ min. Then in the range of 88–110 gray level intensities, the number of pixels exceeded those detected at 0 min. These phenomena represent and feature an enhanced Gd movement.
3.2. Samarium distribution

Fig. 3a and b show the 3D diagrams of the DNR images. Here for technical reasons the DNR images are observed at $t = 15$ and 60 min. In the case of Sm a lateral apoplast transport from the main vascular system towards intercostal tissue can be appraised, presumably involving cell walls and intercellular spaces of mesophyll cells. The semi-quantitative transport may be reckoned from the distribution of pixel counts observed in the interval of 130–155 multigray levels as is evident from Fig. 4.

3.3. Cadmium distribution

In order to estimate the Cd distribution, 2.6 mg Cd dissolved in 1 cm$^3$ D$_2$O was added to the adaxial surface of the main vein of the primordial leaf which can be exactly identified in 2D projection of the 3D diagram of the DNR image. During 30 min period the distribution of the Cd on/in the leaf tissues was being studied. At the 30th minute (Fig. 3d) from the declination of the composition of the plan perceived at $t = 0$ min (Fig. 3c) a main vein movement can be presumed and put forth. This postulation is advocated by the characteristic pixel count distribution. This differed from those noted for either Gd or Sm distribution pattern where lateral translocation was also implicated.

4. Conclusion

In the plant’s nutritional research the in vivo and in situ qualitative and quantitative images on the transport and distribution processes are helpful in revealing the role of the elements. This statement are especially valid for those elements whose biological importance are either less studied or not yet revealed. The Gd, Sm and Cd are included to this group. Till now, according to our knowledge,
distribution patterns in organ and tissues were studied only for Cd. Recently, with X-ray microprobe analysis it was revealed that the cadmium preferably locates in the inner compartment of root cortex cells [14].

In our present study using DNR technique with Sapphire and Iman image processing and analyzing programs in the primordial leaf of the bean distribution patterns for Gd, Sm, Cd from D₂O dripfeed were laid open. The following postulations, regarding qualitative distribution and a semi-quantitative analysis, were applied:

1. The ~100 μm resolution of the DNR technique used made it possible only to follow the long distance apoplastic transport of the investigated
elements. These implicated vascular systems, cell walls and intercellular spaces.

2. The findings obtained are positive affirmable for the leaves.

3. The semi-quantitative analysis of the time kinetics of apoplast transport was based on pixel count distribution histograms of the pertinent gray levels represented areas.

The initial drops of Gd, Sm and that of Cd under our experimental conditions were clearly observed (Figs. 1 and 1d and 3a and c). This observation proves and accentuates the sensitivity and efficacy of our experimental set-up and method.

From the 3D and their 2D projections for the investigated elements and time intervals, the following apoplast transport patterns can be established:

1. The Gd during 60th minute was transported in the main and lateral vascular systems, then there was penetration into the intercostal tissues.

2. The Sm at the same time interval was transported from the initial drop in the direction of lateral tissues possibly involving cell walls and intercellular space.

3. As regards Cd movement, in the course of 30 min, it occurred longitudinally in the main vein Fig. 5.

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References